Heavy Flavor Production Measured by the PHENIX Detector at RHIC

Cesar Luiz da Silva for the PHENIX Collaboration

Iowa State University
e-mail: slash@bnl.gov

Abstract. PHENIX Experiment at RHIC collected large data sets with p+p, d+Au and heavy ion collisions that are used to measure heavy flavor and charmonium production at a center of mass energy of 200 GeV in different rapidity ranges. This proceeding summarize the latest results from PHENIX measurements concerning open and close heavy quark production and their interpretation in view of the current theoretical understanding in this field.

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INTRODUCTION

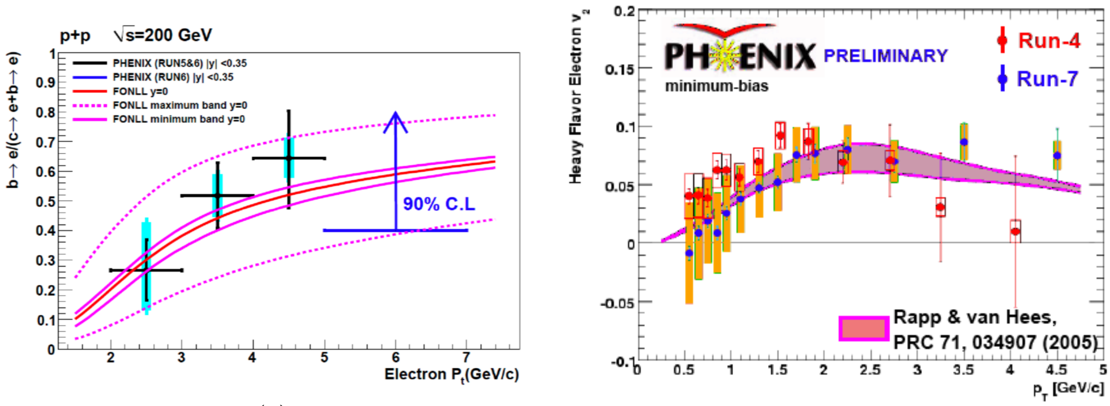
Heavy Quarks(HQ) and charmonium production are important tools for the study of the fundamental properties of QCD. Open charm and bottom observations can test pQCD cross section calculations in point-like collisions and gauge some aspects of the hot dense matter formed in heavy ion collisions like energy loss and medium viscosity. Charmonium production and its suppression in p+Au and d+Au collisions offer an opportunity to observe cold nuclear matter (CNM) effects such as parton distribution modifications and $Q\bar{Q}$ breakup cross sections. Furthermore, the charmonium can be dissociated due to the color screening [1] turning it observation a phase transition thermometer [2, 3]. However, the coalescence of charm quark is likely to modify the charmonium abundance at RHIC energy [4].

PHENIX Detector [5] has been collected data in p+p, d+Au, Cu+Cu and Au+Au collisions and has measured heavy quarks by using non-photonic electron at mid-rapidity and hadron subtracted muon samples at forward rapidity. Charmonium has been detected in different states (J/ψ, ψ' and χ_c) by fully reconstructed leptonic decays at three different rapidity ranges. This proceeding will report these measurements made in collisions at $\sqrt{s} = 200$ GeV and what is expected for the near future.

HEAVY FLAVOR RESULTS.

The measured non-photonic electrons cross section at mid-rapidity [6] is about 1.5 times what is expected from Fixed Order plus Next-to-Leading-Log pQCD calculation (FONLL) [8], but still agrees withing experimental and theoretical errors. The hadron subtracted muons yield at forward rapidity [7] agrees with FONLL for $p_T > 3.5$ GeV/c where the S/B is better.

PHENIX is looking towards to disentangle of D and B contributions in the HQ inclusive measurement at central rapidity. Two preliminary approaches are the electron-hadron correlation and the fitting of the continuum di-electron invariant mass distribution. The bottom fraction of HQ yield agrees with FONLL calculations (Fig. 1-a) within the experimental and theoretical uncertainties.



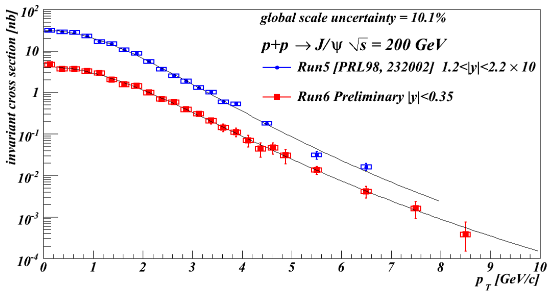
(a) (b)

FIGURE 1. (a)Preliminary bottom fraction of the total HQ measurement obtained by e-h correlation. (b)HQ elliptic flow in Au+Au collisions and corresponding transport model prediction [15].

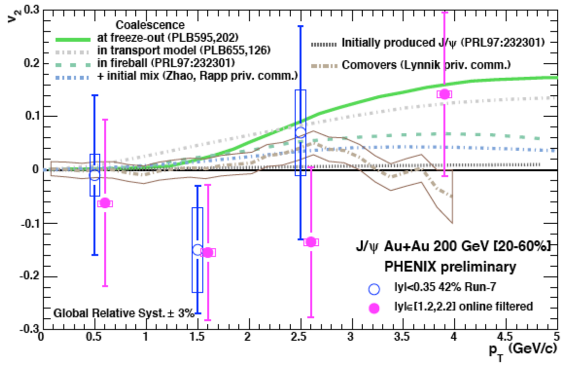
The total non-photonic electron spectrum follows the binary scaling in Au+Au collisions as expected from HQ produced in hard scattering processes [9]. Nevertheless the yield is suppressed at high p_T indicating medium effects like energy loss.

When looking at central collisions in Au+Au [9], the HQ suppression at intermediate p_T is compatible with the so called "dead cone effect" picture where the gluon radiation is unlikely to happen in the forward direction of heavier particles [10]. However, at high p_T the suppression is very similar to that observed for light mesons. This observation suggests that models which can describe very well energy loss of light mesons are not universal. Many corrections and additional tunings have been proposed to provide a complete picture of the energy loss [11, 12, 13, 14].

The Au+Au data also reveals the elliptic flow of HQ as can be seen in the second harmonic Fourier term of the non-photonic electron azimuthal distribution around the reaction plane (Fig. 1-b). Diffusion coefficient in transport models fitted to the observed nuclear modification factor and flow [15, 16] can be used to estimate the viscosity/entropy of the medium formed. Figure 1-b shows the good agreement between the elliptic flow obtained by Rapp and Van Hees's transport model [15] and what is observed at PHENIX. The HQ suppression is also well fitted by the same equation system. The fitted diffusion coefficients returns a viscosity/entropy $\eta/s = [1.3-2.0]$ times the conjecture quantum limit ($\hbar/4\pi$) [17]. For a naive comparison, the same ratio for the water at normal conditions is $380\hbar/4\pi$, for the helium is $9\hbar/4\pi$ [18].



(a)



(b)

FIGURE 2. (a)J/ψ yield at central and forward rapidity in p+p collisions. Distributions are fitted by a function $A\left(1+(p_T/b)^2\right)^{-n}$. (b)Second harmonic Fourier term of J/ψ azimuthal angle referent to reaction plane at central and forward rapidity.

CHARMONIUM RESULTS.

PHENIX published the p_T dependence of J/ψ cross section at central and forward rapidity from the data taken in p+p collisions in 2005 [19]. A much larger p+p data sample was acquired in 2006 and allowed to improve the statistics principally at high p_T. A brand new preliminary result for the central rapidity is already available as can be seen in Figure 2-a. The preliminary central arm results agree very well with that released in [19].

The J/ψ measurements includes feed-down from excited states, namely ψ', χ_c and Bs. PHENIX has released preliminary yield ratio measurements of these particles to J/ψ at mid-rapidity. After use the branching ratio for electrons we found $8.6 \pm 2.5\%$ of J/ψs are from ψ' and up to 42% (90% CL) are from χ_c. The bottom cross section obtained from the e-h correlation studies and its branching ratio to J/ψs returns a contribution of $3.6^{+2.5}_{-2.3}\%$. All these values are in agreement with most of experiments in other collision energies made in other facilities.

Cold nuclear matter (CNM) effects were calculated by using EKS parton modification distribution [21] and breakup cross section with a range between 0 and 5 mb [22]. The results, when compared to the nuclear modification factors of J/ψs in d+Au collisions R_{dA} [20] and extrapolated to Cu+Cu and Au+Au collisions [23], do not allow a serious calculation of the anomalous suppression R_{AA}/CNM. PHENIX has been analysing a new d+Au data with 10 times more statistics which can better constrain the CNM effects.

In the other hand, it is clear the stronger suppression at forward rapidity than that in mid-rapidity in Au+Au collisions [24]. The fitted breakup cross section to R_{dA} has a chance to have different magnitudes in forward and central rapidities [20]. However, recent CNM calculations [25] can reproduce the different suppressions with the same breakup cross section when an extrinsic scheme ($g+g \rightarrow J/\psi + g$) is used for the parton modification calculation. Color Glass Condensate effects can also returns rapidity dependence of the initial state related suppression [26].

The J/ψ suppression pattern observed at $|y| \sim 0$ is very similar to that observed in 10 times lower center of mass collision energy at SPS [28, 27]. This observation needs to be seen with some caveats: The hot and dense matter is expected to be larger at RHIC leading to a stronger J/ψ dissociation due to the color screening; CNM effects can also be different; different feed-down sources to the J/ψ yield can be dissociated [29].

The abundance of charm quarks at RHIC turns the regeneration of J/ψ from uncorrelated $c\bar{c}$ viable, unlikely at SPS energies. This additional J/ψ production channel can compensate the stronger dissociation at RHIC. Regeneration also matches the observation of more surviving J/ψs at central rapidities since it happens more often in this kinematic region [4].

The p_T broadening due to Cronin effect is observed at SPS experiments [28] but it is not so evident at RHIC [23]. This observation can be an evidence for the $c\bar{c}$ regeneration since the Cronin effect is only important for primary J/ψs. The J/ψ anisotropy can be significant if it is formed from regeneration in a considerable fraction [30, 31, 32]. Preliminary observations of J/ψ anisotropy in the most recent Au+Au data (Fig. 2-b) still cannot draw a conclusion for this assumption.

SUMMARY AND OUTLOOK.

The measurement of non-photonic electron spectra has showing the behavior expected from HQ production. Perturbative QCD calculations are in the limit of agreement with the results when considering the PHENIX measurements and theoretical uncertainties. The behavior of the HQ in hot and dense medium suggests some corrections in the energy loss models which well describe the suppression of light mesons. The viscosity of the medium obtained from diffusion coefficients fitted to HQ suppression and flow has shown the matter formed at RHIC is very close to a perfect fluid where its shear stress is only from quantum fluctuations. Future improvements in the HQ measurement will come with the fully reconstruction of D and B mesons by using a silicon vertex detector to track down the vertex decay [33].

The so expected prove of the color screening in charmonium states still relies on a better measurement of CNM effects and understanding of what is the importance of the uncorrelated $c\bar{c}$ recombination in close charms. The incoming improvement in beam luminosities at RHIC-II will access the observation of nuclear modifications of other quarkonium states. It will be a benchmark if is confirmed anomalous suppression of different quarkonia states providing a much better reference for the transition point between normal nuclear matter and the hot and dense environment.

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